Magnetic survey of the Poortown Dolerite, Isle of Man

J. D. A. PIPER[1], A. J. BIGGIN[2] & S. F. CROWLEY[1]
[1]*Department of Earth Sciences, University of Liverpool, Liverpool L69 3BX, UK*
[2]*School of Geological Sciences, University of Kingston, Penrhyn Road, Kingston upon Thames, Surrey KT1 2EE, UK*

Abstract: A ground magnetic survey of a 1.5 × 1 km^2 area surrounding the Poortown Dolerite emplaced into Early Ordovician Manx Group metasediments has identified two regions of high-amplitude and short-wavelength anomalies; the first region extends for 300 m north of the quarry outcrop and the second lies between 100 and 500 m to the east. Linear anomalies have trends ranging from east–west to east-northwest–west-southwest. Palaeomagnetic and rock magnetic studies of the exposed intrusion show that the magnetization resides in Ti-poor titanomagnetite, which is predominantly multidomained. The natural remanent magnetization is dominated by a viscous remanence in the present geomagnetic field and the magnetic anomalies can therefore be modelled using the ambient field direction. A smaller high-blocking temperature component has a westerly direction of negative inclination and is compatible with a normal magnetization acquired during Late Ordovician times. 2D Geometrical models are developed to fit the observed magnetic anomalies. They show that the igneous complex comprises one or two north dipping sheets at its eastern and western peripheries, which expand into a set of multiple sheets separated by screens of Manx Group country rock in the area immediately north of the present quarry outcrop. The sheets may be components of a smaller number of sill-like intrusions repeated by faulting. This general model is supported by results from six boreholes.

The igneous body exposed at Poortown Quarry 3 km east of Peel (National Grid reference [SC 269 832]) is the largest of a suite of basic intrusions emplaced into Lower Palaeozoic rocks of the Isle of Man (Lamplugh 1903). They occur along a north-northeast–south-southwest trend located in the western and southern parts of the island (Fig. 1).

Owing to the poor quality of exposure, the architecture of the Poortown Intrusion is unknown. Lampugh (1903) referred to it as a 'diabase' and proposed that it has the form of a 'lens-like sheet inclining northwestwards', probably on the basis of the prominent ridge-like topographic feature with a southeast facing escarpment which rises above surrounding, relatively flat, cultivated farm land. Exploration of potential quarry reserves based on four boreholes (Holmes Grace Consulting Engineers Ltd 1992) led to the suggestion that a more complex intrusive geometry comprising a series of 'pod-like bodies' exists beyond the confines of the existing quarry.

Further exploration of reserves during 1995 (Davies *et al.* 1995) resulted in aquisition of substantial additional borehole data. Simplified logs of the boreholes are given in Fig. 2 and their locations are shown in Fig. 3. Whilst up to 50 m of

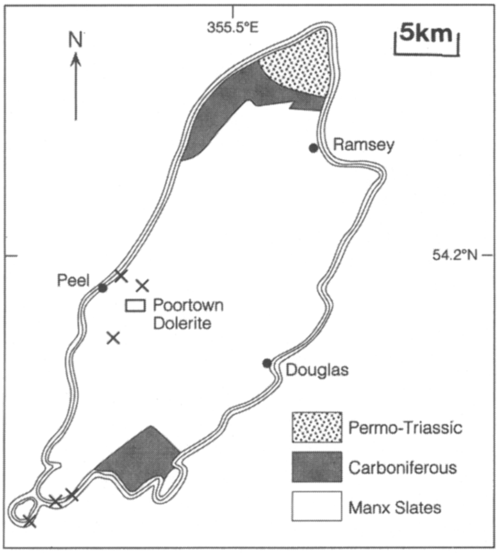

Fig. 1. Regional location of the Poortown Dolerite. The crosses show the distribution of the basic intrusive suite described by Lamplugh (1903).

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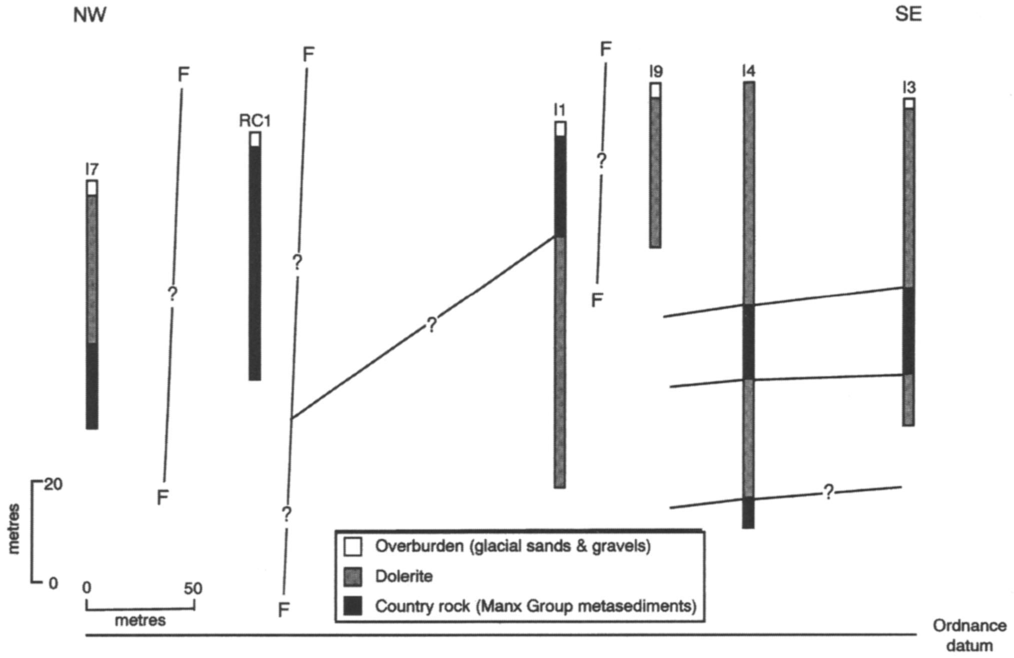
NW
SE
F
F
F
F
F
F
I7
RC1
I1
I9
I4
I3
?
20
0
metres
0
50
metres
Overburden (glacial sands & gravels)
Dolerite
Country rock (Manx Group metasediments)
Ordnance datum

Fig. 2. Distribution of dolerite and Manx Group rocks logged in boreholes in the vicinity of the Poortown Quarry. Locations of the boreholes are shown in Fig. 3.

continuous intrusive body are present in some logs, they show that significant lateral variations in both the distribution and apparent thickness occur over short distances (Fig. 2). The intrusion is evidently not a single unit but consists of at least two sheets separated by Manx Group low-grade metasediments (see boreholes I3 and I4 in Fig. 3).

Interest in the form of the Poortown Intrusion has increased in recent years because it represents the only economic source of roadstone on the Isle of Man. It is also of general interest because improved understanding of the geometry should help to resolve the origin of the dolerite. As a relatively strongly magnetized basic body emplaced into weakly magnetized metasediments, in which paramagnetic chlorite and pyrite appear to be the main inducing phases, a magnetic survey provides an effective geophysical method for establishing the wider extent of the body and forms the main topic of this paper.

Geological background

Although parochially referred to as 'gabbro' (e.g. Ford 1993), the quarried body at Poortown appears to form part of a rapidly cooled, high-level intrusion composed of variable amounts of clinopyroxene and plagioclase in a matrix dominated by chlorite, epidote and carbonate minerals (calcite, Fe-rich dolomite). Despite extensive alteration during low-grade metamorphism, geochemical analyses of least-altered samples from the quarry indicate equivalent primary rock compositions ranging from high-Mg tholeiitic to calc-alkaline basalt and basaltic andesite of possible arc-related origin (Power & Crowley 1999). Within this overall textural and geochemical context the Poortown Intrusion is more correctly described as a dolerite.

Examination of the quarry exposure identifies sharp, sill-like contacts which are conformable with the bedding in Manx Group country rock (Fig. 4). The chilled margin is thin (*c.* 5 cm) and grades from a microcrystalline lithology containing sparse millimetre scale pyroxene phenocrysts into a more coarse-grained porphyritic rock which forms an outer zone to the equicrystalline centre of the intrusion. Although the country rock (particularly the sand-dominated quartzitic beds) is locally silicified within a few metres of the contact, there is no evidence of significant growth of contact metamorphic aluminosilicate minerals.

Deformation in the form of repeated faulting of the intrusion is evident from: the occurrence of

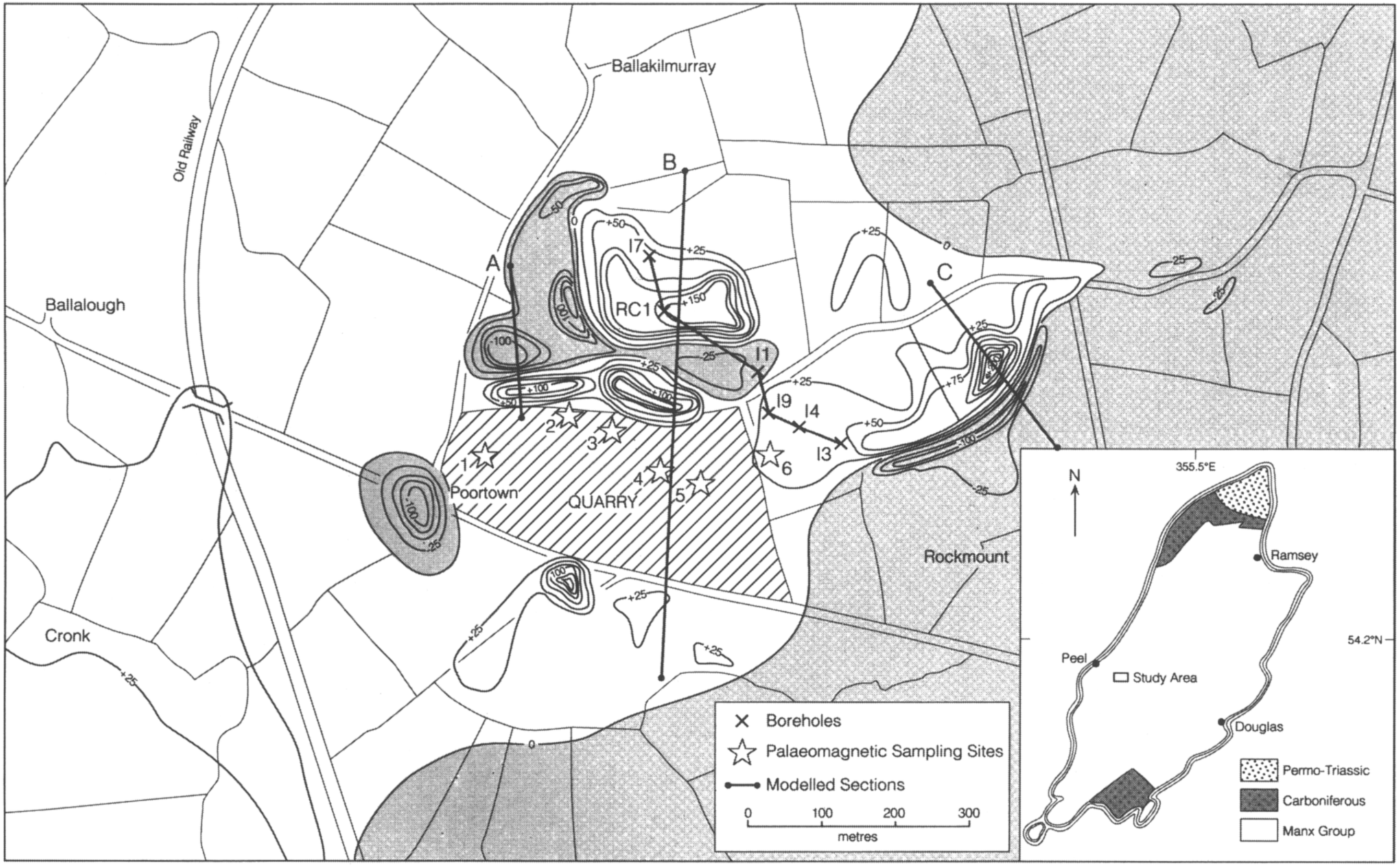

Fig. 3. Regional location and magnetic anomaly map of the Poortown district, Isle of Man. The smoothed total field magnetic anomalies are plotted with a contour interval of 25 n T relative to a base value of 48 881 nT. The three-lettered lines are the profiles fitted by the modelling as described in the text. Parameters for the magnetic modelling are derived from palaeomagnetic samples drilled in the quarry exposure at locations shown by the stars. Borehole locations are also indicated and refer to the logs shown in Fig. 2.

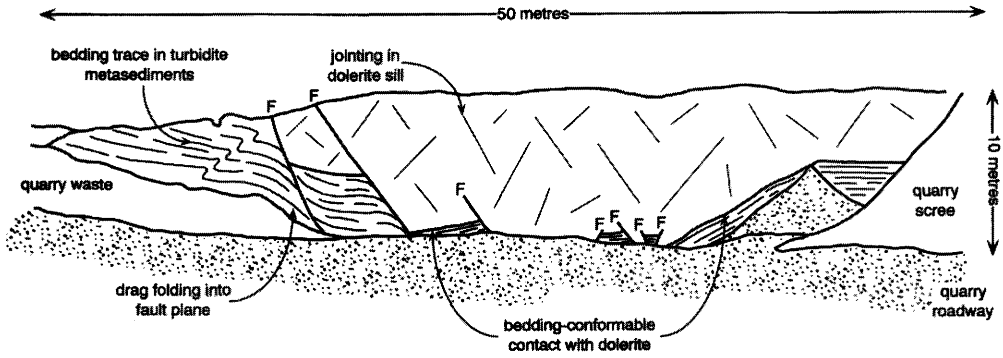
50 metres
bedding trace in turbidite metasediments
jointing in dolerite sill
F
F
F
F F F F
quarry waste
drag folding into fault plane
bedding-conformable contact with dolerite
quarry scree
quarry roadway
10 metres

Fig. 4. Composite field drawing showing relationships between dolerite and Manx Group country rocks in the north face of the Poortown Quarry

steep, scarp surfaces in fields immediately east of the quarry; sharp changes in the dip of bedding and drag folding of Manx Group country rock (Fig. 4); numerous well-developed slickensided surfaces mineralized with hematite and calcite exposed on quarried blocks of the dolerite; and the apparent offset of intrusive bodies between adjoining borehole records (cf. boreholes I4 and I1, and RC1 and I7 in Fig. 2).

Although displacements on specific faults which juxtapose dolerite and Manx Group are obvious (Fig. 4), many *in situ* fault planes are difficult to identify in the quarry walls. However, sufficient evidence is available to indicate a near-vertical, orthogonal fault set, with metre scale displacements, oriented approximately north–south and east-northeast–west-southwest. Close to some faults, phenocrysts present in porphyritic dolerite exhibit textures consistent with the development of ductile shear bands in which stretched and flattened phenocrysts are drawn into fault plane alignment. Shear bands of this type occur frequently in cores recovered from a horizontal borehole (referenced RC4) drilled into the north face of the quarry near the northeast corner; these are accompanied by extensive alteration and replacement of primary dolerite mineralogy by carbonates. A further important observation from dolerite cores is the apparent occurrence of chilled margin contacts within the body of the intrusion, suggesting that it may consist of multiple intrusive sheets as opposed to simple sill-like units.

There is no direct evidence for the age of the Poortown Dolerite. Although not pervasively foliated, a fabric defined by shape orientation of chlorite is approximately parallel to a cleavage in the adjoining Manx Group (Power & Crowley 1999) and suggests that the dolerite was emplaced early in the history of the group.

The magnetic survey

The regional magnetic survey was conducted by pacing long traverse lines designed to establish the extent of the dolerite outwards from the quarried outcrop. To provide a basis for modelling the geometry of the intrusion, the survey was extended well into adjoining regions underlain by Manx Group country rocks. A proton precession magnetometer reading the magnitude of the ambient total magnetic field directly in nanotesla (nT) to an accuracy of 0.1 nT was used for the survey. Traverse lines were surveyed by pacing lines between reference points on the 1:10 560 scale topographic map. Fields were mostly surveyed between their corners and along trajectories following their perimeters at a fixed distance away, usually 50 m, to avoid magnetic interference from fences and field boundaries. The magnetic field was recorded at intervals of 10 paces, reduced to 5, 2 or 1 paces in regions of steep gradients. A base station was visited at intervals of 1–2 h during the survey period to identify variations of the geomagnetic field during the survey intervals.

The survey lines were extended into regions where the magnetic field was flat or comprised small random variations which identified the probable presence of underlying Manx Group rocks. Regions of high-amplitude and short-wavelength anomalies were recognized as being due to artificial noise from the quarry, roads, the derelict railway line, wire fences and some sections of the bridle tracks. These sections of the survey lines were excluded from compilation of the magnetic base map. Other magnetic anomalies due to non-geological sources correlated with the overhead powerlines and underground cables related to quarry activities crossing the region;

these were found to influence the survey for up to 8 m on either side and comprise narrow bands of excluded information on the base map. Because some fields west of the track leading to Ballakilmurray (see Fig. 3) were in-crop at the time of the survey, this area was only partially surveyed. Accordingly, it has not been contoured, although no magnetic anomalies of > 25 nT were recognized by the limited surveying in this region.

Over 1800 stations were recorded during the survey. The resultant data were processed in three steps: (1) removal of temporal variations of the geomagnetic field; (2) filtering of 'noisy' segments of the profiles to suppress short-wavelength anomalies; (3) subtraction of the regional background field.

Diurnal changes in the ambient magnetic field were recognized from the base station measurements recorded at intervals during the field survey – corrections of up to ±20 nT were required to cancel effects of this variation. Short-period fluctuations which could not be excluded on the grounds of an obvious artificial source were smoothed over 50 m data sets using a five-point filter. Since the survey covered a relatively small area, the regional background was taken to be the average field value recorded over the Manx Group country rocks and determined to be 48 881 nT. This value is subtracted from the field values to derive the magnetic anomalies.

Reduced values were plotted on an expanded copy of the 1:10 560 map and sampled for two levels of interpretation: (1) a contour map was produced joining values of equal field strength, at intervals of 25 nT, to permit a qualitative regional interpretation; (2) the three profiles located in Fig. 3 were compiled to run approximately orthogonal to the trend of the anomalies and provide a basis for magnetic modelling.

Regional extent of the Poortown Complex

The regional survey shows two areas of strong near-surface magnetization (Fig. 3): the first extends for 300 m north of the present quarry and the second lies between 100 and 500 m to the east-northeast. These zones of high-amplitude and short-wavelength anomalies are surrounded by magnetically flat ground which is interpreted to be underlain by Manx Group metasediments only. The eastern anomaly is a curvilinear feature and changes from +220 to −80 nT in just 40 m; it is located across a prominent topographic feature where strongly magnetized dolerite is probably upfaulted to the north against weakly magnetized slates to the south. The anomaly to the north of the quarry comprises several positive and negative features, probably attributable to interleaving of intrusions and country rock (cf. Fig. 2). With the exception of two small non-linear features, there are no anomalies south of the quarry and road, and any extension of the intrusion in this direction must lie at depth.

Magnetic properties of the dolerite

A palaeomagnetic and rock magnetic study of the Poortown Dolerite has been conducted on 62 cores drilled at six sites in the vicinity of the quarry (see locations in Fig. 3). The rock magnetic experiments show that the remanence carrier is Ti-poor titanomagnetite. The magnetic structure of this mineral is predominantly multidomained but significant fractions of single domains are also present. The ubiquitous presence of magnetite in the dolerite is confirmed by petrographic study (Power & Crowley 1999). The total natural remanent magnetizations (NRM) show considerable scatter which, in this instance, may include viscous remanent magnetizations (VRM) acquired during four months of laboratory storage (Fig. 5). However, NRM directions tend to have positive inclinations with northerly to westerly declination. The mean direction ($D/I = 335/48°$; cone of 95% confidence, $\alpha_{95} = 10°$; precision parameter, $k = 4.4$) has a shallower inclination and more westerly declination than the present geomagnetic field; this implies that remanence recorded by the NRM is typically the vector resultant of a VRM in the present field and a smaller high-blocking temperature component.

Progressive thermal demagnetization (Fig. 6) demonstrates that NRM are composite and comprise of one or more low-blocking temperature components plus a high-blocking temperature component of probable ancient, and possible primary, origin. This is recognized in typical component structures (Fig. 6) which show a northerly positive magnetization unblocked over a broad range of temperatures up to 400°C to isolate a negative westerly component over a much narrower temperature range (typically 520–560°C). Directions of the subtracted low blocking temperature components are seldom precisely in the present Earth's field direction (Fig. 5), but collectively they yield a mean ($D/I = 355/62°$, $\alpha_{95} = 6$, $k = 9.6°$) with identical declination to the present field and an inclination which is only marginally shallower. This is better defined than the mean of the NRM because it excludes the high-unblocking temperature components.

The high-blocking temperature components yield a mean direction of $D/I = 266/-48°$ ($\alpha_{95} = 5°$, $k = 18$). It does not correlate with any post-Lower Palaeozoic field direction from the British Isles and, since Britain lay in the southern hemisphere

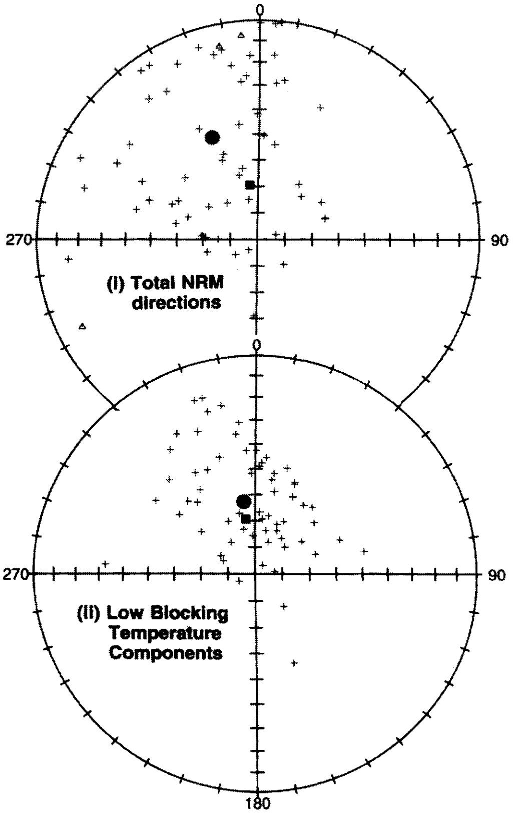

Fig. 5. Distributions of total NRM directions of magnetization in the Poortown Gabbro and subtracted low-blocking temperature components. +, Plots on the lower hemisphere; △, plots on the upper hemisphere; ●, the mean directions of the distributions; ■, direction of the present geomagnetic field in the study region.

prior to Carboniferous times, it is equivalent to a normal polarity. The polarity and palaeolatitude (29° S *in situ*) are compatible with acquisition during Late Ordovician times (cf. Piper *et al.* 1997), although, in view of the alteration and deformation of the dolerite, this is likely to be of secondary origin. This conclusion relates magnetization, and possibly basic magmatism, on the Isle of Man to Caledonian tectonomagmatic activity of this age in North Wales and the Lake District. Emplacement at a late stage of the closure of Iapetus would be compatible with the arc-related chemistry (Power & Crowley 1999). Unfortunately, the palaeomagnetic solution remains uncertain because possible post-magnetization tilting of the complex is unknown; the direction of this ancient component of magnetization cannot therefore be defined unambiguously.

Although a high-blocking temperature remanence divergent from the present field direction is present in the quarried dolerite, it is the smaller fraction (typically one-quarter to one-third) of the total NRM. Because the induced magnetization is also in the present field direction, and typically larger than the remanent contribution, for purposes of modelling the magnetization of the body it may be taken to be in the direction of the ambient geomagnetic field. The volume susceptibilities of the cores measured using a Bartington Bridge range from 0.02 to 1.00×10^{-3} SI units. Since this range includes three orders of magnitude, the results are best summarized by a log 10 normalized distribution (Irving *et al.* 1966), which yields a mean and standard deviation of $0.54 \pm 0.26 \times 10^{-3}$ SI units. The intensities of magnetization before treatment show a corresponding variation in the 0.05–4.20×10^{-2} A m^{-1} range; the log mean value is $1.9 \pm 0.52 \times 10^{-2}$ A m^{-1}.

Models for the magnetic anomalies

Of the three profiles used for modelling (see locations in Fig. 3), A is interpolated from the contour map, and lines B and C are compiled directly from reduced field profiles with suitable orientations. B is derived by aligning two separated traverses (the central part could not be surveyed because the quarry intervenes) in an attempt to model the full width of the intrusive complex. Profile C is used to model the eastern anomaly at Rockmount. These profiles comprise input to the *GRAVMAG* program and the model is developed as a series of polygons to match the observed anomalies. The model is described as 2.5D because a half-strike is entered for the whole model and the polygons are constrained to continue on either side of the 2D profile for this distance. All polygons were assigned the same magnetic properties using values derived from the field and laboratory study: geomagnetic field strength 48 880 nT; magnetic susceptibility 0.54×10^{-3} SI units; intensity of remanent magnetization 1.9×10^{-2} A m^{-1}; direction of remanence, *D/I* = 353/70°. A half-strike of 300 m was used, although the selected value was found to have little influence on the models provided that it exceeded a few tens of metres.

Profile A (Fig. 7) requires at least two near-surface intrusions dipping to the north to match the observed profile. Polygon 1 may imply a faulted south margin. Although it appears unrealistic for a geological feature, it stresses that the magnetized volume diminishes rapidly to the north at this point and may be faulted out altogether. Profile B crosses the most complex part of the anomaly (note that the short-wavelength features are smoothed on the

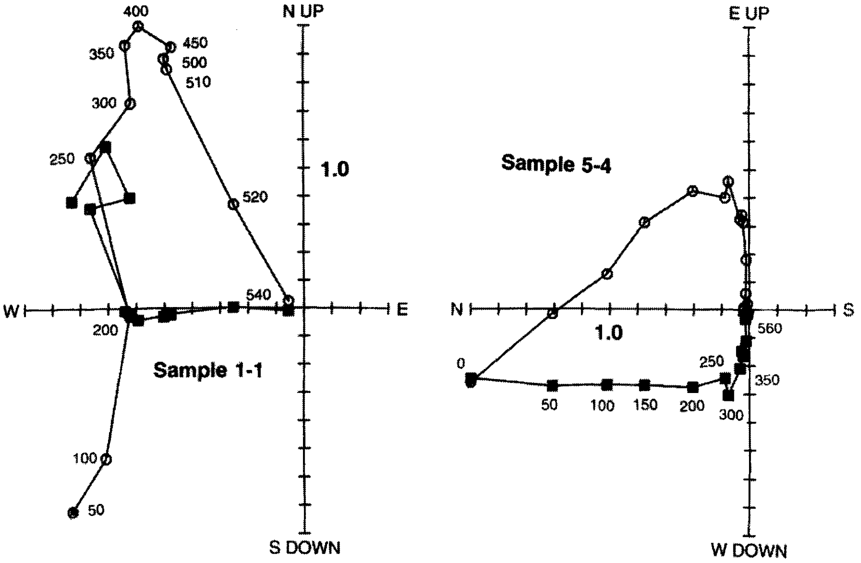

Fig. 6. Thermal demagnetization results from two samples of the Poortown Gabbro plotted as orthogonal plots with the magnetization vector projected on to the horizontal (■) and the vertical (○) planes. Demagnetization steps are indicated in °C and axes are calibrated in units of × 10^{-5} A m^2 kg^{-1}. Note that the northerly positive magnetization acquired in the present geomagnetic field is subtracted by treatment to 300–400°C to recover a high-unblocking temperature convergent component with westerly direction and negative inclination.

regional map of Fig. 4). Added complexities to the modelling procedure come from the space occupied by the quarry and the fall in topography from north to south; the latter point could not be accommodated by the modelling and level ground is assumed for the profiles shown in Fig. 7. This limitation does not affect the main features of the model which requires a series of northerly dipping sheets, each a few tens of metres in thickness, separated by screens of non-magnetic country rock to explain the oscillations in the profile. Because a number of variables is involved, these models are inevitably a compromise and should be interpreted in general, rather than specific, ways. Thus, the presence of dolerite across the floor of the quarry has not been accommodated; attempts to link the bodies with horizontal polygons at this level produced a deterioration in the fit, although the geometry of the sheets was only affected in detail. It is concluded that the sequence of sheets required to explain the magnetic anomalies are either: (1) connected to a single body at a depth greater than the modelling in Fig. 7; or (2) parts of one or more original sill-like bodies which have been repeated by faulting.

A model fit to line C is shown in Fig. 7 where polygons 1 and 2 suggest a possible sill and feeder. Whilst a third body is required to the south to produce the fit shown, this is excluded from the figure because it is an artefact of the arbitrary background and is not supported by the flat magnetic field around Rockmount (Fig. 3).

Conclusions

The presence of a strongly magnetised basic intrusion at Poortown, emplaced into essentially non-magnetic Manx Group country rock, makes magnetic survey the most suitable method for mapping the intrusion in unexposed terrain. The survey identifies a continuation of the intrusion to the north and east of the quarry outcrop and shows that extraction can potentially extend into this ground. However, high-amplitude and short-wavelength anomalies show that the unexposed complex comprises a number of dipping sheets; extraction will therefore need to contend with screens of country rock. The presence of a dominant viscous magnetization in the dolerite, acquired in the present geomagnetic field and compounded with an induced magnetization, permits the form of the intrusive complex to be modelled. The modelling shows that a simple form at the east and west peripheries, probably comprising two north dipping bodies, exapands into a sequence of multiple sheets in the region immediately north of the present quarry. The sheets

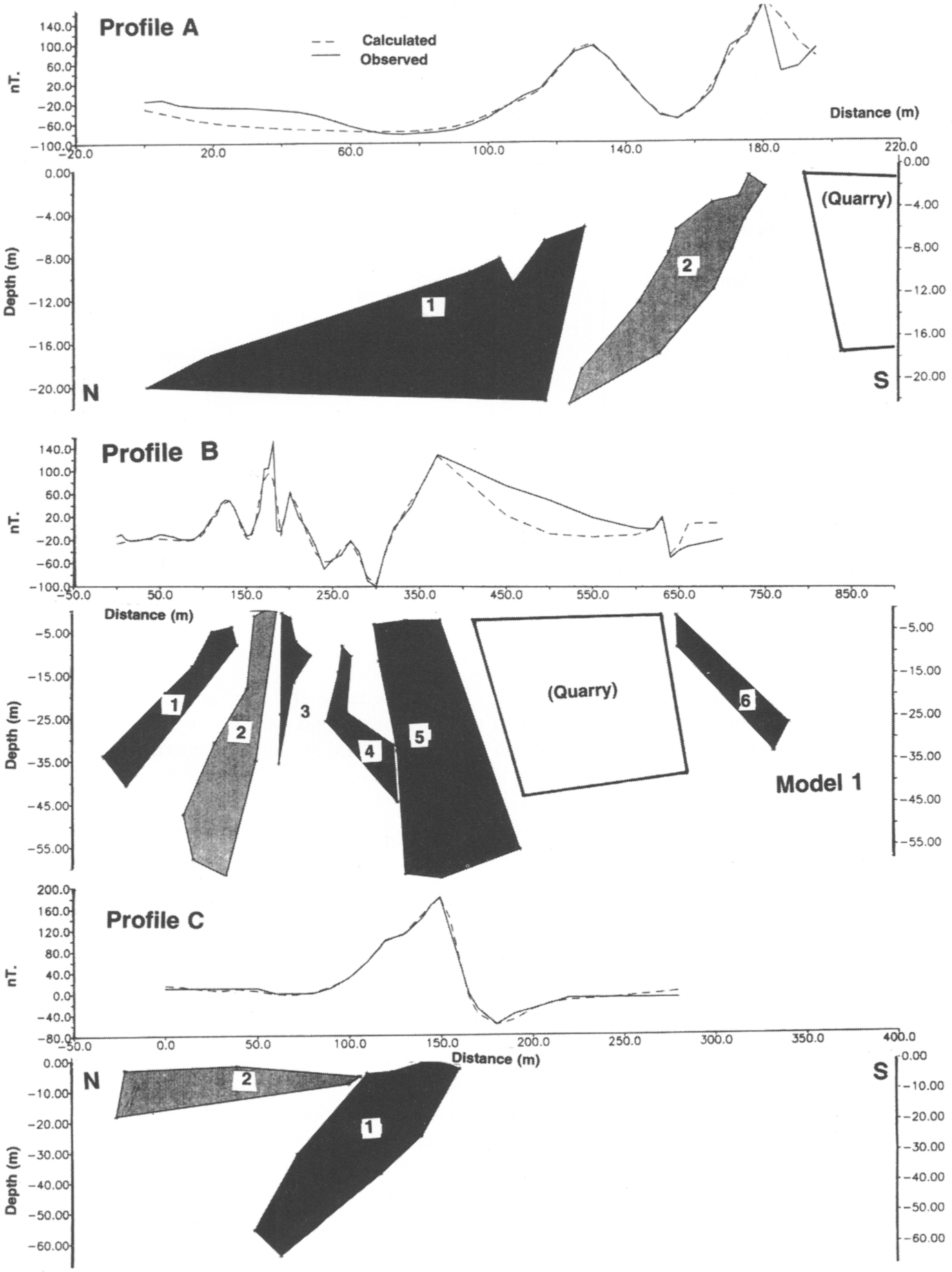

Fig. 7. Magnetic profiles A–C across the Poortown Complex (see Fig. 3 for locations) with 2D polygonal models derived to fit the observed anomalies. Magnetic parameters assigned to the polygons are given in the text and the vertical exaggeration is 5.3.

are typically a few tens of metres in thickness and attain a maximum thickness of *c.* 80 m; variations in intensity and susceptibility within the bodies would, of course, influence the thicknesses derived from the modelling.

We are grateful to local landowners in the Poortown district for allowing us to conduct the magnetic survey on their land, the Department of Highways, Properties and Ports for allowing us to collect samples in the quarry, and to G. S. Kimbell and an anonymous reviewer for their valued criticisms of the manuscript.

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